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CORRELATION ANALYSIS OF FIRST PHASE MONITORING RESULTS FOR URANIUM MILL WORKERS

by

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CORRELATION ANALYSIS OF FIRST PHASE MONITORING RESULTS FOR URANIUM MILL WORKERS

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ABSTRACT

This report describes the determination of the existence and extent of correlations in data obtained during the first phase study of urinalysis, personal air sampling and lung burden measurements of uranium mill workers. It was shown that uranium excretions in urine as determined from spot urine samples at the end of the shift were correlated with intakes calculated from personal air sampling data at the 90% confidence level. When there are large variations in the rate of urine production. the time rate of uranium elimination was shown to be a more reliable indicator of uranium excretion than the uranium concentration in urine. Based on correlations between phantom and subject lung burden measurements in the presence of changing background radiation levels, a comparative lung burden measurement technique was developed. The sensitivity and accuracy of the method represent a significant improvement and the method is as applicable to females as to males.

RÉSUMÉ

Ce rapport rend compte de l'existence et de l'ampleur des corrélations de données obtenues suite à la phase initiale d'étude de l'analyse d'urines, de l'échantillonnage d'air individuel, et de la mesure de la charge aux poumons chez les travailleurs des usines de concentration d'uranium. On a démontré que la présence d'uranium dans les échantillons intermittents d'urines à la fin de la période de travail est en corrélation avec l'incorporation calculée à partir des données d'échantillonnage de l'air individuel à un niveau de précision de 90%. Quand il y a des variations importantes du taux de production d'urine, le débit d'élimination d'uranium est un indicateur plus sûr du rejet d'uranium que la concentration même d'uranium dans l'urine. On a élaboré une technique comparative de mesure de la charge aux poumons en se fondant sur des corrélations entre les mesures de la charge aux poumons de fantômes et celle de sujets en présence de fonds de rayonnement variables. La sensibilité et la précision de cette méthode représentent une amélioration importante et cette méthode s'applique aux deux sexes.

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1. INTRODUCTION

During the summer and fall of 1982 the Atomic Energy Control Board funded a study at two uranium mills which was carried out by Monserco Limited. The purpose of the first phase study was to evaluate the feasibility of applying to uranium mill workers the existing bio-analytical techniques (first established for uranium fuel fabrication workers) for identifying uptakes and measuring retention of uranium in occupational environments. The results of that study have been published in a separate document (Ref. 1). This report describes additional analysis to investigate the existence and extent of correlations of data obtained during the above study. The scope of work consists of identifying and assessing functional correlations among the personal air sampling, spot urinalysis and continuous urinalysis data. Also, this work is to identify and assess the correlations in subject/phantom lung counting measurements and to interpret the effect of these correlations on the accuracy and sensitivity of the lung counting measurement technique.

2. EXPERIMENTAL PROGRAM AND RESULTS

The experimental program, described in more detail in Ref. 1, included a total of 12 subjects, 6 from each of the two facilities. The subjects were all above ground workers in the mill environment and were exposed to one or both of magnesium and ammonium diuranate. There was continuous coverage, while at work, of all the subjects throughout the five week study. Workers who used respirators or other protective breathing devices were excluded from the study so that there would be the highest probability of direct relationships between air, urine and lung measurements.

Urine samples were collected from all subjects on a regular basis using either of two collection regimes. One sampling regime consisted of a continuous 72 hour period during which

each and every voiding was collected in a separate specimen bottle. The subjects recorded the date and time of voiding. Each specimen was analysed separately for uranium and the volume was measured. Throughout the remainder of the five week study period each subject gave a urine specimen immediately before starting each work shift and another immediately after showering and changing clothes at the end of each shift. For both specimens the subjects were requested to empty the bladder completely and to record the time of voiding and the time of the last previous voiding. The uranium concentration in urine in µg U/L and the urinary throughput in µg U/h are given for each subject in columns 4 through 9 in Tables 1-1 to 7-1.

Throughout the five weeks of the study, each of the 12 subjects was issued a personal air sampler with a new filter for each work shift. The impactor filter heads were of CANMET design and using a flow rate of 1.9 litres per minute passed only respirable size particles with a mass distribution similar to a horizontal elutriator (see Figure 1). The air pumps were SIMQUADS manufactured by Cassella and controlled flow rate pumps from Dupont. Type A-E glass fibre filters were used to collect the respirable size particles. The operating time of the SIMQUADS was determined by means of the counter.

The amount of uranium inhaled by the subject while the pump was on, was calculated using the expression:

$$I1 = 20 \times A / 1.9 \qquad (1)$$

where 20 = respiration rate of Reference Man doing light work in L/min (Ref. 4)

A = amount of respirable uranium collected on the personal air filter in µg U

1.9 = personal air sampler rate in L/min

It was assumed that the average uranium concentration in air,

measured while the personal air sampler was on, persisted throughout the full 8 or 12 hour shift. Therefore, the total uranium inhaled during the shift was calculated by:

$$I2 = I1 \times S / T \qquad (2)$$

where S = duration of shift in hours

T = sampler operating time in hours.

When the Dupont personal air samplers were used, pump operating time was assumed equal to the length of the shift. The SIMQUAD air samplers were issued to subjects who worked both 8 and 12 hour shifts whereas the Dupont samplers replaced defective SIMQUADS on 8 hour shifts only. The Dupont samplers were designed for 12 hour operation and easily covered the shorter shift. The uranium intakes I1 and I2 are recorded in columns 2 and 3 respectively in Tables 1-1 to 7-1.

Lung burden determinations were made on each of the 12 subjects throughout the last four weeks of the study. Measurement times for each subject were split between the beginning and the end of the work shift. The measurement procedure (Ref. 3) required that the subject change into a set of clean clothes and then lie supine in the mobile shielded bed. Two phoswich detectors were positioned 8 cm above the center of the lungs and a 33 minute measurement was made. Either before or after the measurement of the subject, a background measurement was made using a water phantom. The gamma spectra of both subjects and the water phantom were divided into five energy intervals and the counts integrated. The integrated counts for subject 11 and the water phantom are given in columns 3 to 7 of Table 9. The lung burdens were calculated according to the procedure M21 (Ref. 3) and have been reported in Reference 1. It was noted that most were not real burdens but artifacts caused by external contamination.

3. PERSONAL AIR SAMPLING AND URINALYSIS CORRELATIONS

3.1 CONTINUOUS URINALYSIS

The data collected during the continuous urinalysis part of the program was analysed to investigate in detail the urinary excretion of uranium during and after exposure to airborne uranium. In Figures 3-1 and 3-2, the urinary output of uranium on Sept. 20/21 by subject 22 is shown. Each horizontal bar ends at the time of voiding and begins at the time of the last previous voiding. The position of the bar on the y axis represents the magnitude of the uranium concentration in urine or the uranium output per hour calculated for the time interval represented by the length of the bar in the x direction.

The uranium output per hour, shown in Figure 3-1, represents a smooth curve which rises steeply during the workshift, peaks about two hours after the end of the shift and then drops quickly to about the pre-shift level. The continuity of the data which forms the rising part of the curve was determined by correlating consecutive sets of uranium output per hour results assuming a linear relationship (U per hour at t_1 versus U per hour at t_2, where t_1 and t_2 are consecutive voiding times). The first data set consisted of the uranium output per hour determined at the 8:07 a.m. (t_1) voiding and at the 10:40 a.m. (t_2) voiding; the second data set consisted of the uranium output per hour determined at the 10:40 a.m. (t_1) voiding and at the 1:15 p.m. (t_2) voiding, etc. The correlation coefficient was calculated to be 0.84 for the six data sets and is significantly different from zero at the 95% confidence level. The significance of the correlation is determined by comparing the calculated correlation coefficient to the critical value as described in the Appendix. For six data sets the calculated coefficient must be greater than a value of 0.74 for a 90% level of confidence and greater than a value of 0.81 for a 95% level of confidence. The correlation coefficient of 0.84 therefore, indicates a significant correlation.

The urinary output by subject 22 on Sept. 20/21, as expressed in uranium concentration in urine is shown in Figure 3-2. There is significant scatter, with no real trend indicated. The same type of correlation analysis, as described in the paragraph above, was calculated using the uranium concentration in urine parameter. The correlation coefficient was calculated to be -0.32 for the six data sets and is not different from zero at the 90% confidence level.

The erratic results of the uranium concentration in urine measurements compared to the uranium output per hour result is not surprising when the variation in the urine production rate is investigated. The rate ranges from 35 to 384 mL/h during Sept. 20/21 with an average and standard deviation of 180 and 107 mL/h respectively.

The urinary output of uranium on Sept. 20/21 by subject 24, as shown in Figures 4-1 and 4-2, is consistent when expressed either as uranium concentration in urine or as uranium output per hour by the kidneys. This agreement is to be expected in this case because the subject's urine output only ranges from 58 to 83 mL/h with an average and standard deviation of 67 and 9.3 mL/h, respectively. There were too few data sets to make meaningful correlation calculations in this case. This data could be used to test retention and elimination models, however, that is beyond the scope of this work.

The continuous urine sampling results from the remaining subjects were higher during the shift than before or after but the uranium levels were so close to the detection limit that no meaningful calculations could be performed.

3.2 SPOT URINALYSIS

The approach used here to correlate the personal air and urinalysis results was based on the results described above

and a cursory inspection of the data which indicated fast urinary clearance. It was postulated that the urinary through put of the subjects following an intake via inhalation could be approximated as shown in Figure 2. In this idealized case it is assumed that the intake occurs throughout the shift and uranium begins to appear in the urine almost immediately. The occurrence of the peak uranium throughput by the kidneys in relation to the end of the shift (i.e. the end of the intake) will depend on the degree of solubility of the uranium compound, the time of exposure during the shift and the individual physiology. For example, an intake of highly soluble uranium at the beginning of a work shift with no subsequent intakes during the shift may result in a peak uranium throughput by the kidneys before the end of the shift. On the other hand, an intake of less soluble uranium near the end of a shift may result in a maximum throughput long after the end of the shift.

The testing program called for a urine sample from each subject at the beginning of shift (BOS) and at the end of shift (EOS). There were variations of 1 or 2 hours in sampling times. Therefore, in some cases a BOS sample also represented an EOS+12 hours sample or an EOS+16 hours sample after the previous days work shift depending on whether the shift duration was 12 or 8 hours. Using the simple model in Figure 2, several combinations of urinalysis results were chosen for correlation with the uranium intake represented by the personal air sampling results. The EOS urinalysis measurements were correlated with the personal air sampling measurements and the results are given in Tables 1-2 to 7-2. The correlations between the inhaled uranium and the differences between the EOS and the BOS urinalysis measurements are given in Tables 1-3 to 7-3. The correlations between the inhaled uranium and the differences between the EOS and the EOS+12 hr (or EOS+16 hr) urinalysis results are given in Tables 1-4 to 7-4. Correlations between the inhaled uranium and the differences

between the EOS+12 hr and the BOS urinalysis results are given in Tables 1-5 to 7-5.

Correlation calculations were made using the data collected on subjects 11, 12 and 15 from facility 'A' and subjects 21, 22, 24 and 25 from facility 'B'. The correlation coefficients are summarized in Tables 8-1 to 8-2. The urinalysis data on the other five subjects in the study was generally at or below the minimum detection levels and therefore not amenable to correlation analysis.

3.3 DISCUSSION

The test to determine the best method for calculating the magnitude of the uranium inhaled during a working shift based on personal air sampling yielded positive results. Inspection of Table 8-2 shows that only 9 sets of correlations were statistically significant at the 90% confidence level or higher. In preparing the Table 8-2 correlations the operating time of the pump was assumed to be the exposure time of the subject for the purposes of calculating the amount of uranium inhaled. On the other hand, inspection of Table 8-1 shows 15 sets of correlations were statistically significant at the 90% confidence level or higher. In preparing the Table 8-1 correlations it was assumed that the total exposure time was the actual length of the shift (8 or 12 hours) and that the average air concentration was the same as that determined while the personal air sampler was operating. It was concluded that it is necessary to operate the personal sampling pumps throughout the full shift or at least have scalers record the actual operating time.

Ambiguous results were derived from the test to determine which units are best for quantifying the uranium output in urine. Inspection of Table 8-1 shows that when EOS urinalysis results are considered, the µg U/h units correlated with intake more

often than did the μg U/L units by 4 to 3. However, when EOS-BOS urine output is considered the situation is reversed by 3 to 1. Considering the results shown in Figure 3-1 and 3-2, it should be concluded that μg U/L units will correlate as well with intake unless the individual habitually has a large variation in urine output or a normally consistent individual contributes a specimen at a highly irregular and unusual rate.

The urinary output of uranium as determined by EOS samples correlated significantly with intake only slightly more frequently than EOS-BOS output. Inspection of the urinary concentrations at the BOS shows that except in the cases of subjects 22 and 24 the uranium output in BOS samples was so low that the correction was ineffective. It is concluded that in these cases the BOS correction is not necessary.

4.0 LUNG MEASUREMENT CORRELATIONS

4.1 CORRELATIONS BETWEEN WATER PHANTOM AND SUBJECT LUNG COUNTS

Background radiation levels within the lung counter, caused in part by natural background radiation outside the counter, were monitored by repeated measurements of a water phantom. Throughout the four week period during which lung measurements were made, the water phantom counts varied over a range of 30% (well beyond the uncertainty due to counting statistics, $2\sigma = 2.6\%$). Correlation analysis was made on the data from the lung counts of each subject and the corresponding water phantom measurements.

The lung counting results for subject 11 and the water phantom measurements are given in Table 9. For each energy interval a straight line was fitted to the pairs of data by least squares method (Ref. 5) and a correlation coefficient was calculated (Ref. 2). The critical value of the correlation coefficient is 0.82 at the 90% confidence level and 0.88 at the 95% confidence level for 5 data sets (Ref. 2). Therefore, only the data sets of the lowest energy interval, 10-38 keV,

do not exhibit a statistically significant correlation between the subject's lung measurement and the phantom measurement. The data sets within each of the four higher energy intervals, which have correlation coefficients ranging from 0.95 to 0.99, do exhibit statistically significant correlations at greater than the 95% confidence level. The water phantom and subject 11 lung measurement data for the energy interval 38 to 110 keV have been plotted in Figure 5-1. The energy interval from 38 to 110 keV is especially of interest because the 63 and 93 keV gamma rays from U238(Th234) occur in this region. The line determined by least squares and the 95% confidence limits are shown. The slope of the line was calculated to be 0.95 with an uncertainty of ±0.31 at the 95% confidence level. As expected, the slope is not significantly different than unity. The intercept of 3223 ±2037 (95% confidence level) subject counts at zero water phantom counts results from the subject's natural radioactivity burden of K40, Cs137, etc. The water phantom contained no radioactivity and only scatters radiation from within the shielded counter into the detector.

The water phantom and subject 11 lung measurement data for the energy interval 110 to 165 keV have been plotted in Figure 5-2. The slope of the least squares determined line is 0.90 ±0.19 at the 95% confidence level (Ref. 5). It also is not significantly different than unity. As above, the positive intercept of 1207 ±702 (95% confidence level) subject counts results from the natural radioactivity burden of the subject.

The correlation between the absolute value of the subject 11 lung counts and the water phantom measurements establishes the significant linear relationship between the two. All variations in lung counts were attributable to variations in background radiation. This is consistent with the very small intakes of uranium via inhalation (see column 2, Table 1-1) and with lung burdens calculated using procedure M21 (Ref. 3)

(all less than 6 mg uranium). The correlation also determines that external contamination was not present on subject 11 to interfere with lung burden determinations.

The water phantom and lung counts for all other subjects were examined for analysis. However, in all cases at least one measurement of each subject resulted in an elevated count which was inconsistent with the linear relationship established for subject 11. Because there were too few data sets for correlation analysis on an individual basis, the data was analysed by other techniques as described below. External contamination was identified on all other subjects in at least one of their lung burden measurements. The rates of inhalation of uranium, calculated from personal air sampling measurements, and rates of elimination, calculated from urinalysis, preclude the assignment of the measured uranium to lung burdens.

4.2 COMPARATIVE MEASUREMENTS TO DETERMINE CHANGES IN LUNG BURDEN

Using the approach shown in Figure 5-1, a method can be constructed to measure changes in uranium lung burden by making comparative measurements on the same subject. Background variations can be compensated for by phantom measurements. A line fitted by least squares can be used to predict expected subject counts for "no lung burden" under different background conditions. Values for the subject 11 lung counts were calculated using the least squares equation and the results are shown in column 3 of Table 10. Also the differences between the calculated and observed subject counts were calculated and are shown in column 4. The standard deviation was calculated to be 141 counts (division by n-2 because two degrees of freedom were used in calculating the slope and intercept of the least squares line). The sample standard deviation of 141 counts can be converted to 1.64 mg U by multiplying by the calibration factor which has been measured using the Rando phantom (Ref. 3).

Using this comparative technique, changes in lung burdens as

small as 3.3 mg U can be detected at the 95% confidence level (two standard deviations) under the background conditions experienced during the study. This is a significant improvement of both sensitivity and accuracy over the M21 technique for the following reasons. The comparative technique eliminates the uncertainties in model fitting which is required using M21 in order to compensate for the specific thorax size of the subject. Also, the M21 technique utilizes counts of lower relative statistical significance in the 110-165 keV region to predict the subject background in the 38-110 keV region. The comparative technique operates on only the counts of higher statistical significance in the 38-110 keV region of both the subject and phantom spectra. Another important advantage of the comparative technique is that it can be applied equally as well to females as to males.

Since only changes in lung burden can be detected by the comparative technique, it cannot be used to determine absolute lung burdens unless the initial lung burden is known. (Absolute lung burdens were calculated using the M21 technique.) If lung counting is to be a monitoring requirement, the need for pre-employment or pre-exposure lung burden determinations is obvious.

4.3 CORRELATIONS BETWEEN EXCESS COUNTS IN 38-110 KEV AND 110-165 KEV REGIONS OF LUNG COUNT SPECTRA

The lung burden measurements of all the subjects were analysed with the aim of determining the ratio of the excess counts in the 110-165 keV region to the excess counts in the 38-110 keV region. This ratio is dependent on the length of time that has passed since thorium was removed from the uranium product which was found on the subject. After separation thorium-234 grows in to equilibrium with U238 with a half-life of 24 days. During the decay of U235, gamma rays are emitted at energies of 185, 163, 143 and 110 keV. When efficiency calibrations of the Monserco Lung Counter were carried out, the ratio of uranium

counts in the 110-165 keV region to the counts in the 38-110 keV region was calculated to be 0.120 with a standard deviation of 2.4% (Ref. 3). The uranium calibration sources used in the Rando phantom from the Radiation Protection Bureau of Health and Welfare Canada were sufficiently old that Th234 was in equilibrium with U238.

As shown above, subject 11 had no measurable uranium in or on his person during any of the 5 lung burden measurements. All variations in observed counts were attributable to background changes. Therefore, data from subject 11 was not included in the following calculations. The remaining 11 subjects had uranium contamination on their person during at least one of their lung counts. For a given subject, the absolute value of the excess counts was calculated by subtracting the "cleanest" spectrum of that subject from the "contaminated" spectrum after normalizing to account for differences in background between the two measurement dates. The normalization was achieved through the use of the results of the appropriate water phantom measurements.

The excess counts in the spectra for subjects 12 to 16 are plotted in Figure 6. The correlation coefficient was calculated to be 0.78 for the 17 data sets and was statistically significant at >95% confidence level. The slope of the line (and therefore the ratio 110-165 keV to 38-110 keV integrals) was calculated to be 0.40 ±0.26 at the 95% confidence level. Assuming that the contamination on the subjects was only uranium, the Th234/U238 ratio was 0.30 which occurs 12 days after thorium separation.

The excess counts in the spectra for subjects 21 to 26 are plotted in Figure 7. The correlation coefficient was calculated to be 0.94 for the 16 data sets and was statistically significant at >95% confidence level. The slope of the line (and therefore the ratio 110-165 keV to 38-110 keV integrals) was calculated to be 0.30 ±0.09 at the 95% confidence level. Again assuming

that the contamination on the subjects was only uranium, the Th234/U238 ratio was 0.40 which occurs 18 days after thorium separation. These ratios are significantly lower than the 0.6 to 0.7 that were reported in Reference 1 and are in closer agreement with the expected Th234/U238 ratios after processing of the ore.

5. CONCLUSIONS

Uranium excretion rates calculated from end of shift minus beginning of shift urinalysis for three subjects correlated with uranium intakes calculated from personal air sampling results with a level of confidence of 90% or more.

Uranium excretion rates calculated from end of shift urinalysis for four subjects correlated with uranium intakes calculated from personal air sampling results with a level of confidence of 90% or more. This does not contradict the first conclusion because in most cases the beginning of shift urinalysis results were at or below the detection level.

A component of yellowcake was identified which has a combined intake, retention and elimination half-time of a few hours.

When there are large variations in the rate of urine production, the time rate of uranium elimination was shown to be a more reliable indicator of uranium excretion than the uranium concentration in urine.

Uranium intakes are best determined using results based on a personal air sampler which operates throughout the full shift. If the sampler only operates for part of the shift it should be equipped with a scaler to indicate operating time. The intake should then be calculated using an exposure time equal to the length of the shift and a concentration based on the pump operating time.

There is a high correlation (>95% confidence level) between variations in measurements of background from subjects and water phantoms when external background radiation fields change.

A comparative lung burden measurement method utilizing water phantoms improves the sensitivity and accuracy of the lung counting technique. The minimum detectable change in lung burden is 3.3 mg U under the conditions in this study compared to the minimum detection level of 6 mg U with procedure M21. The standard deviation at the minimum detection level is reduced from 3 to 1.6 mg U.

The comparative lung burden technique has the added advantage that it is as applicable to females as to males.

Radioactive contamination levels observed during lung counting displayed activity count ratios in 110-165 keV region to 38-110 keV region of 0.4 to 0.3. If the contamination is only uranium these values are consistent with Th234/U238 activity ratios of 0.3 and 0.4 respectively.

6. REFERENCES

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FIGURE 1

AIRBORNE PARTICULATE PENETRATION OF CANMET IMPACTOR FILTER HEADS

(similar to horizontal elutriator)

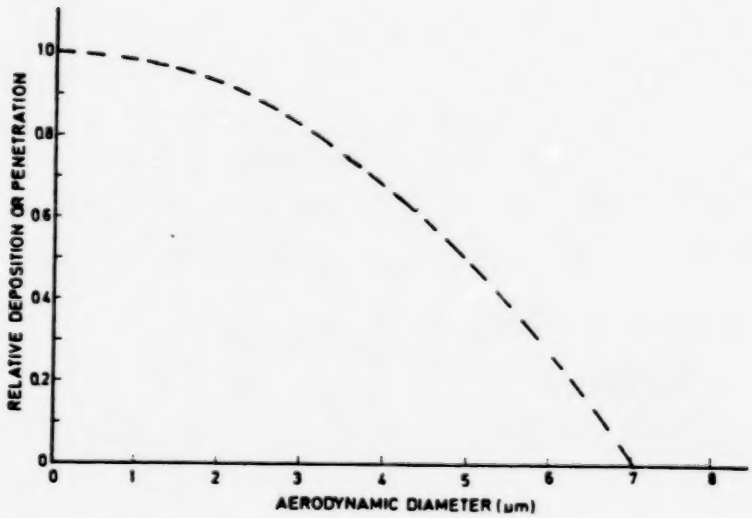
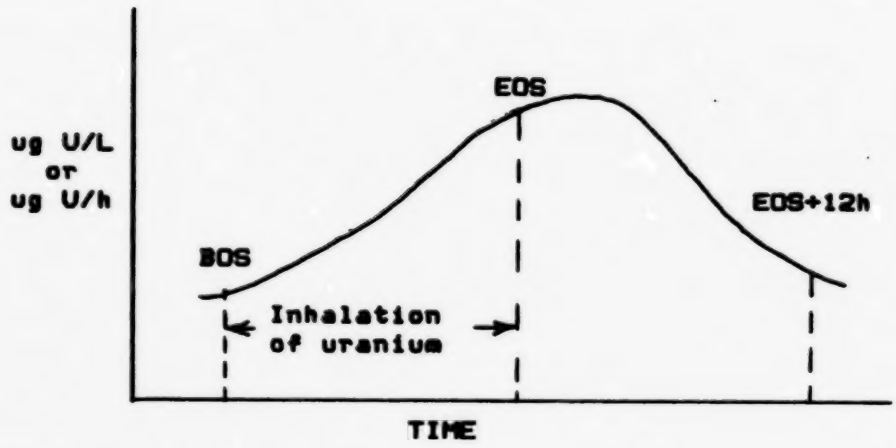


FIGURE 2

IDEALIZED URINARY THROUGHPUT OF INHALED URANIUM



BOS = beginning of shift

EOS = end of shift

EOS+12h = end of shift plus 12 hours

FIGURE 3-1

URANIUM OUTPUT PER HOUR IN URINE, SUBJECT 22, SEPT20/21

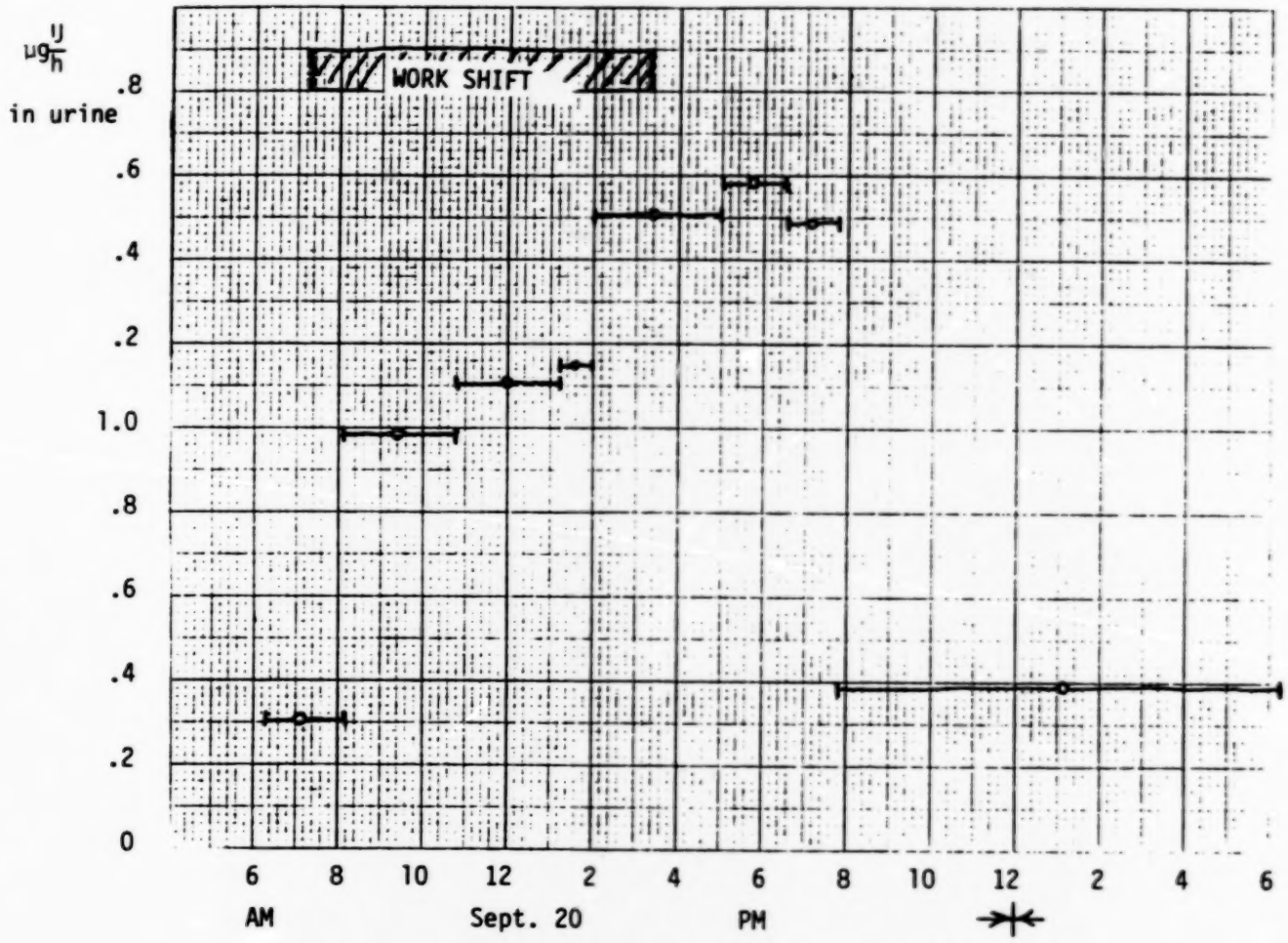


FIGURE 3-2

URANIUM IN URINE CONCENTRATION, SUBJECT 22, SEPT 20/21

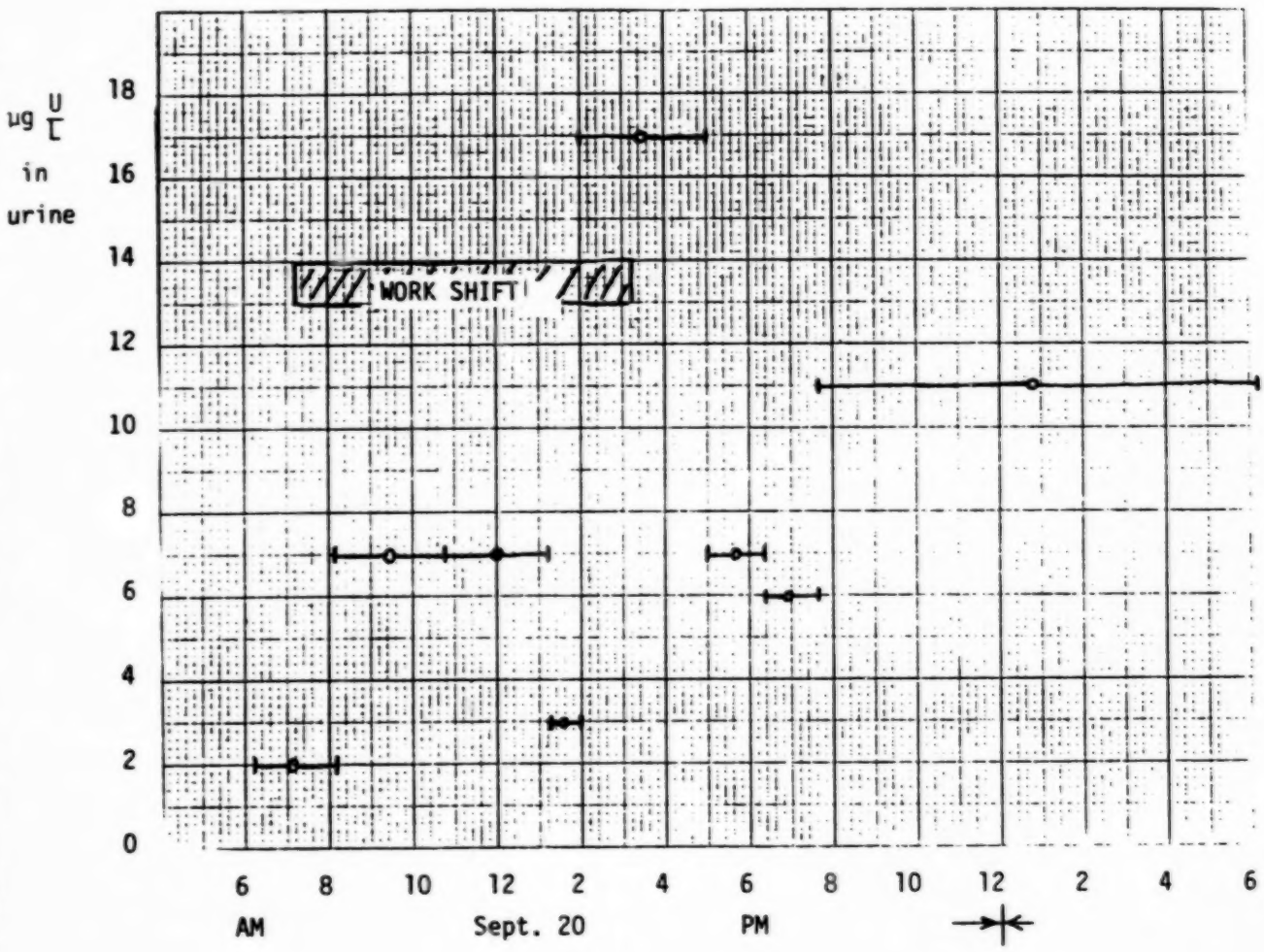


FIGURE 4-1

URANIUM OUTPUT/HOUR IN URINE, SUBJECT 24, SEPT. 20/21

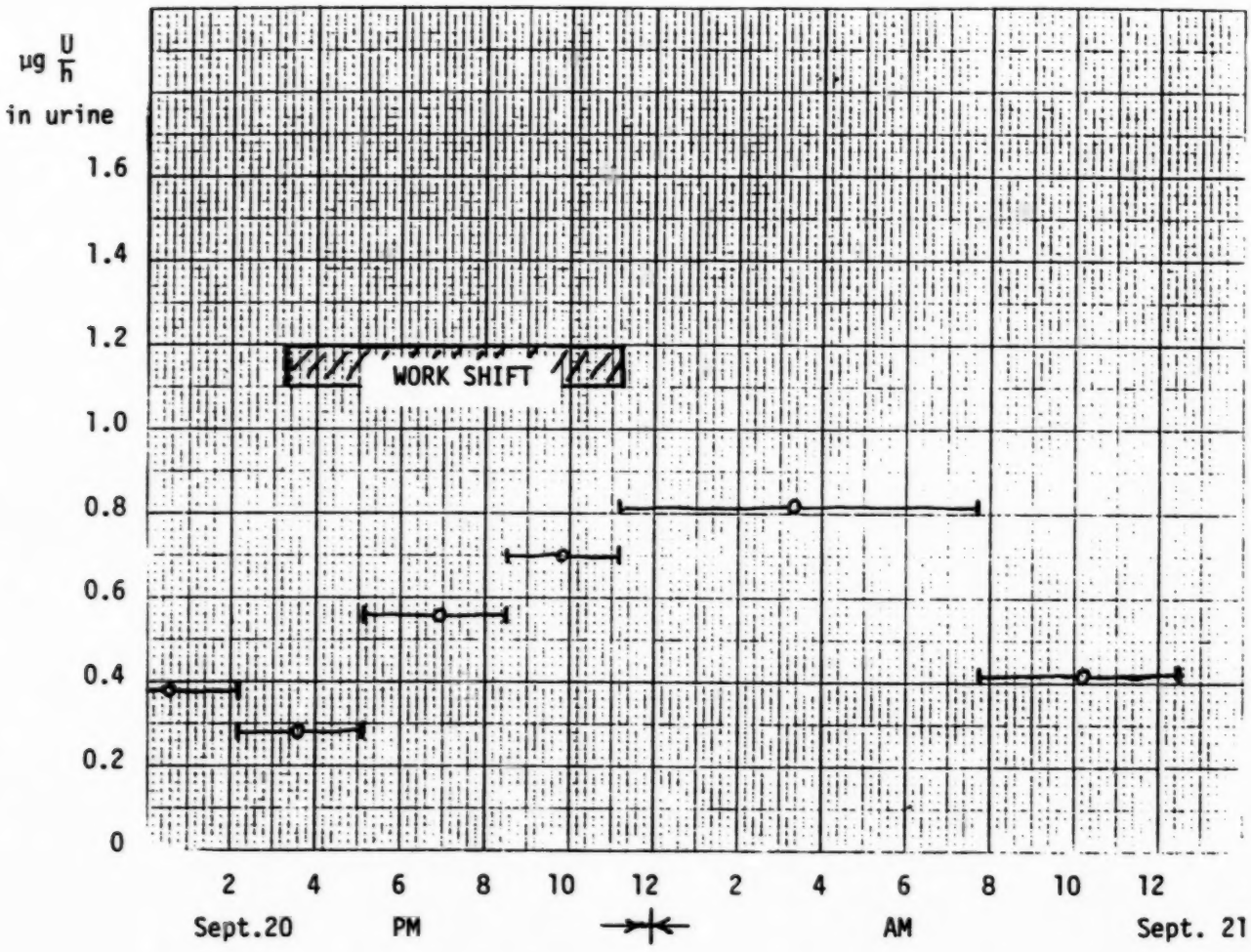


FIGURE 4-2

URANIUM IN URINE CONCENTRATION, SUBJECT 24, SEPT. 20/21

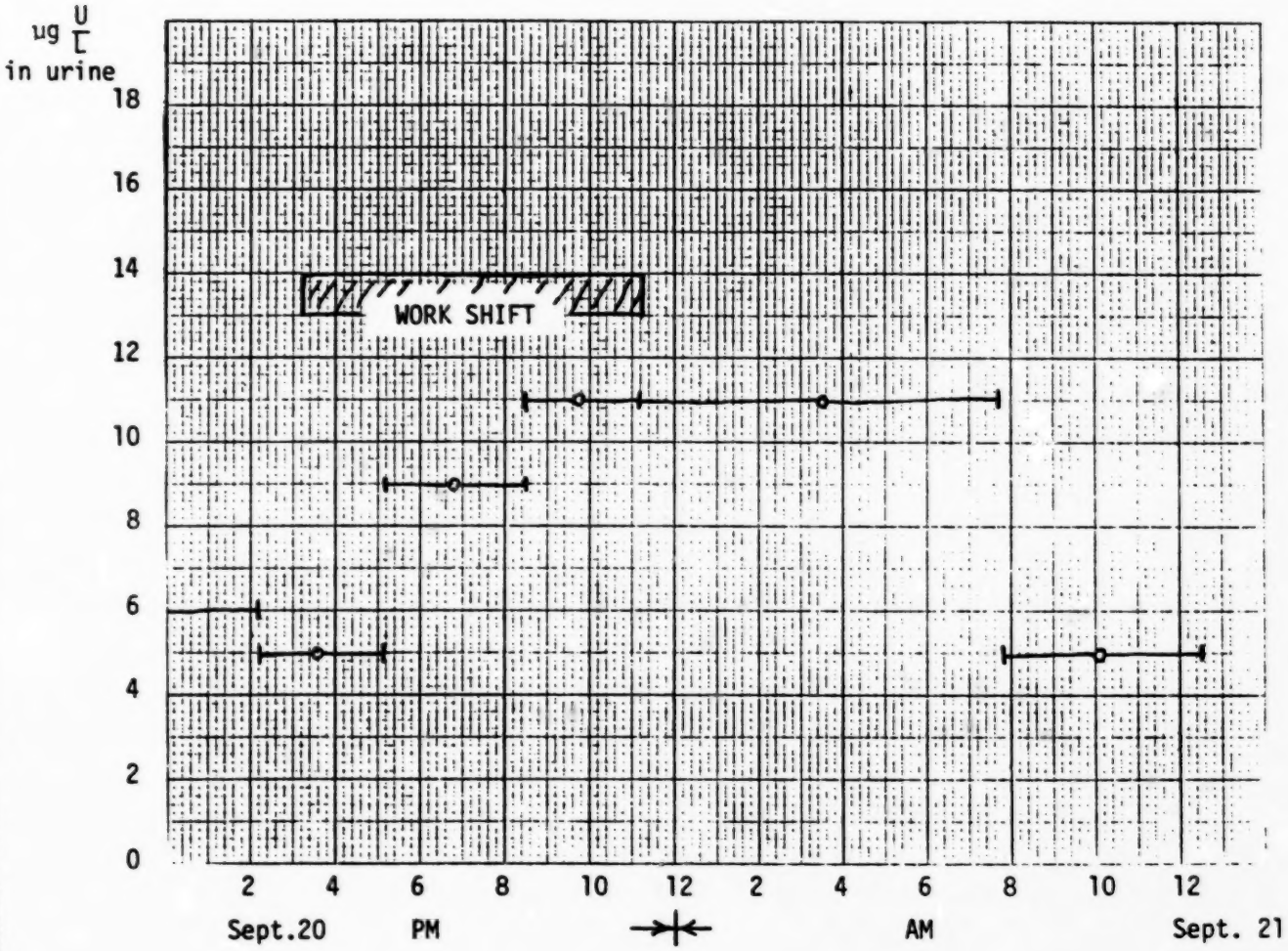


FIGURE 5-1

Correlation Between Subject 11 Lung Counts and Water Phantom Measurements
38 to 110 keV Region

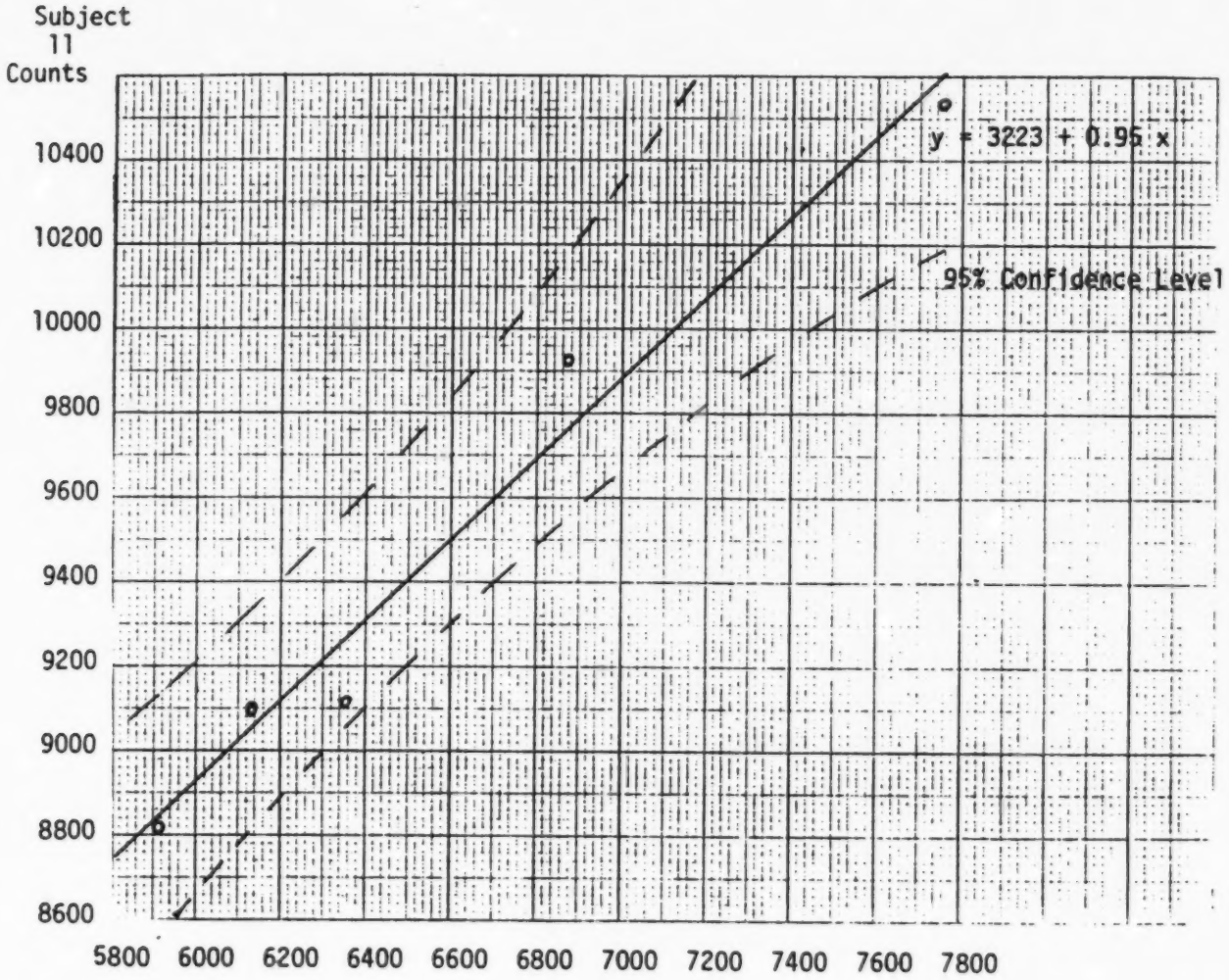


FIGURE 5-2

Correlation Between Subject 11 Lung Counts and Water Phantom Measurements
110 to 165 keV

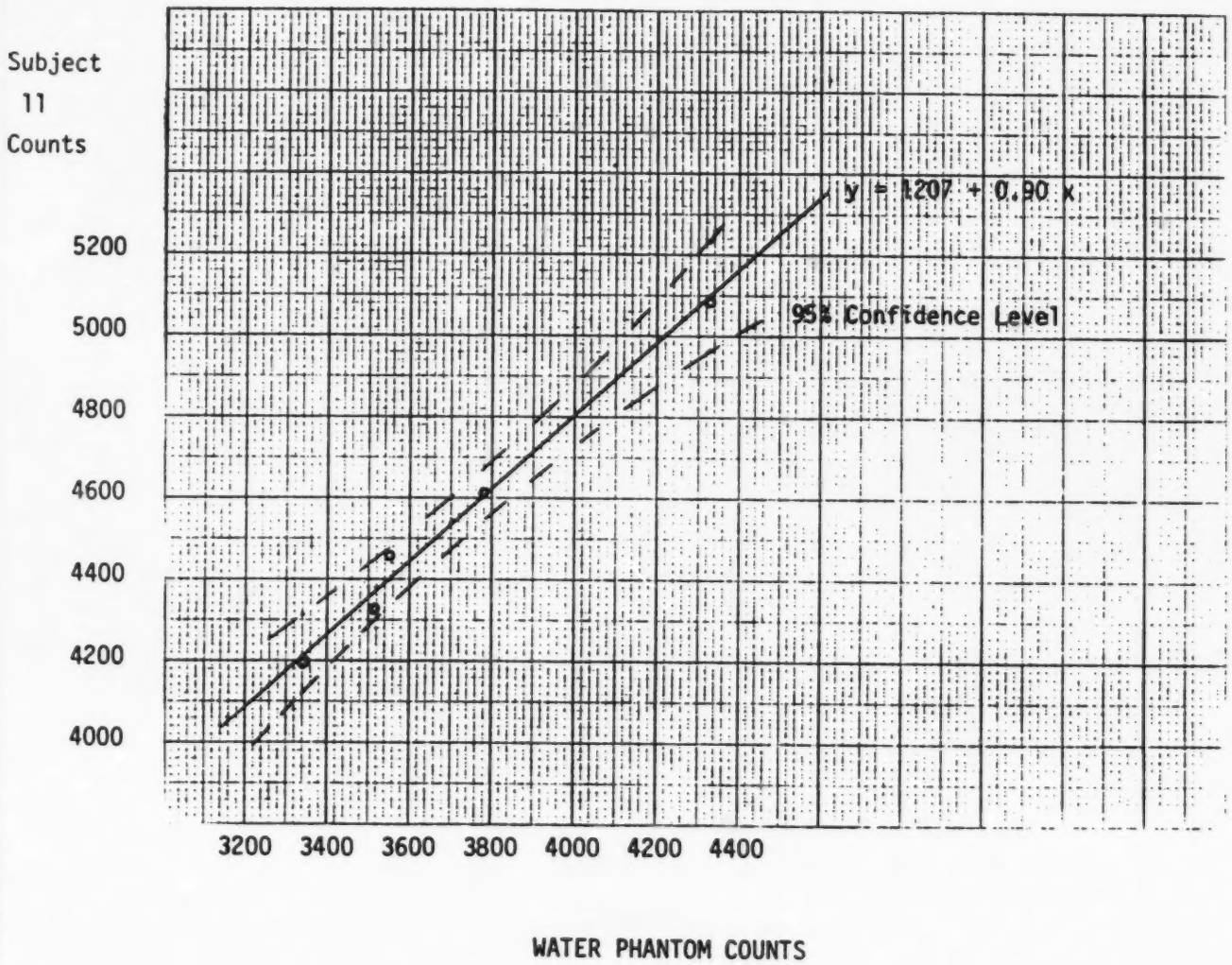


FIGURE 6

Correlation Between Excess Counts in the 38-110 keV Region and the Excess Counts in the 110-165 keV Region of the Lung Measurement Spectra from Subjects 11 to 16.

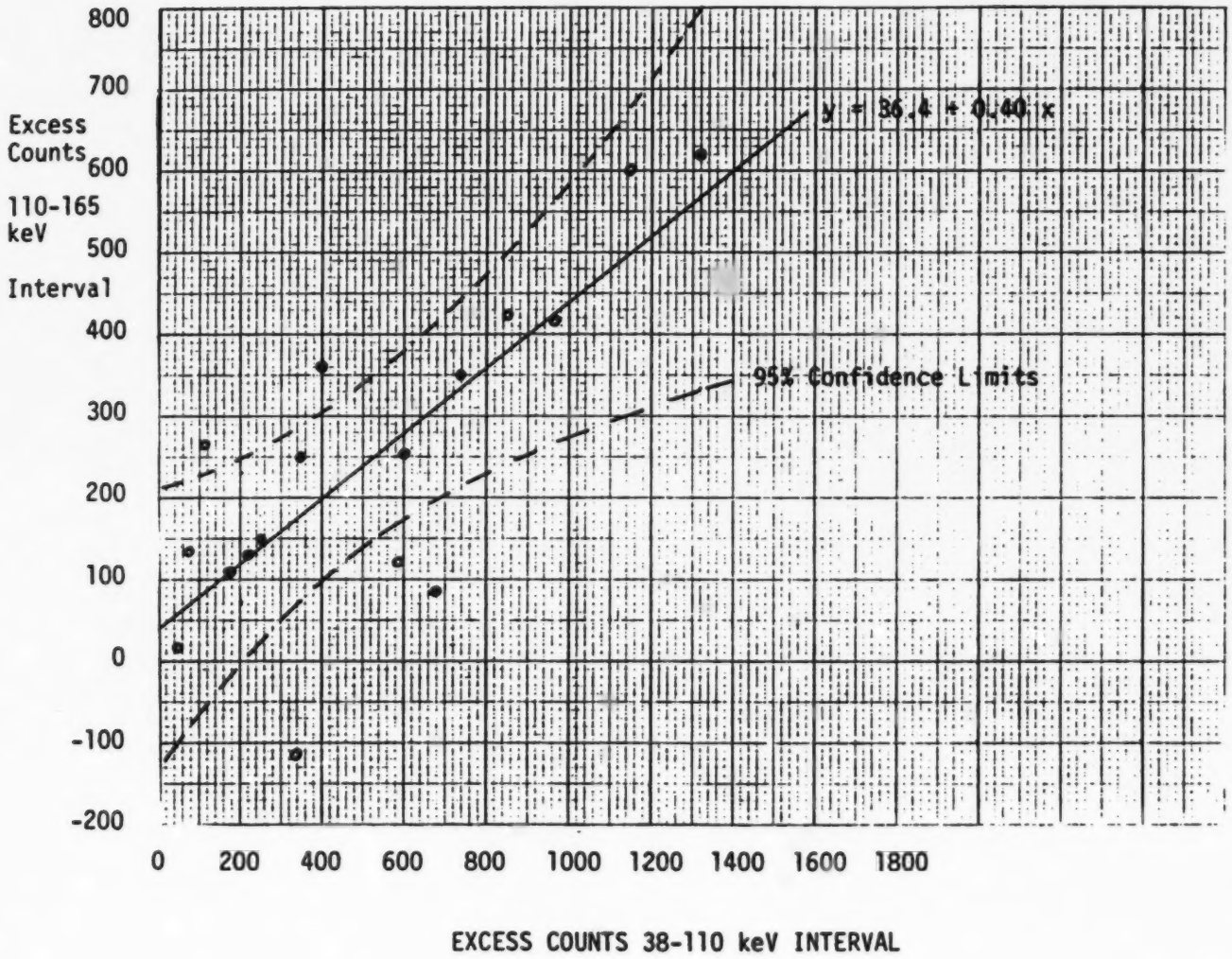


FIGURE 7

Correlation Between Excess Counts in the 38-110 keV Region and the Excess Counts in the 110-165 keV Region of the Lung Measurement Spectra for Subjects 21-26.

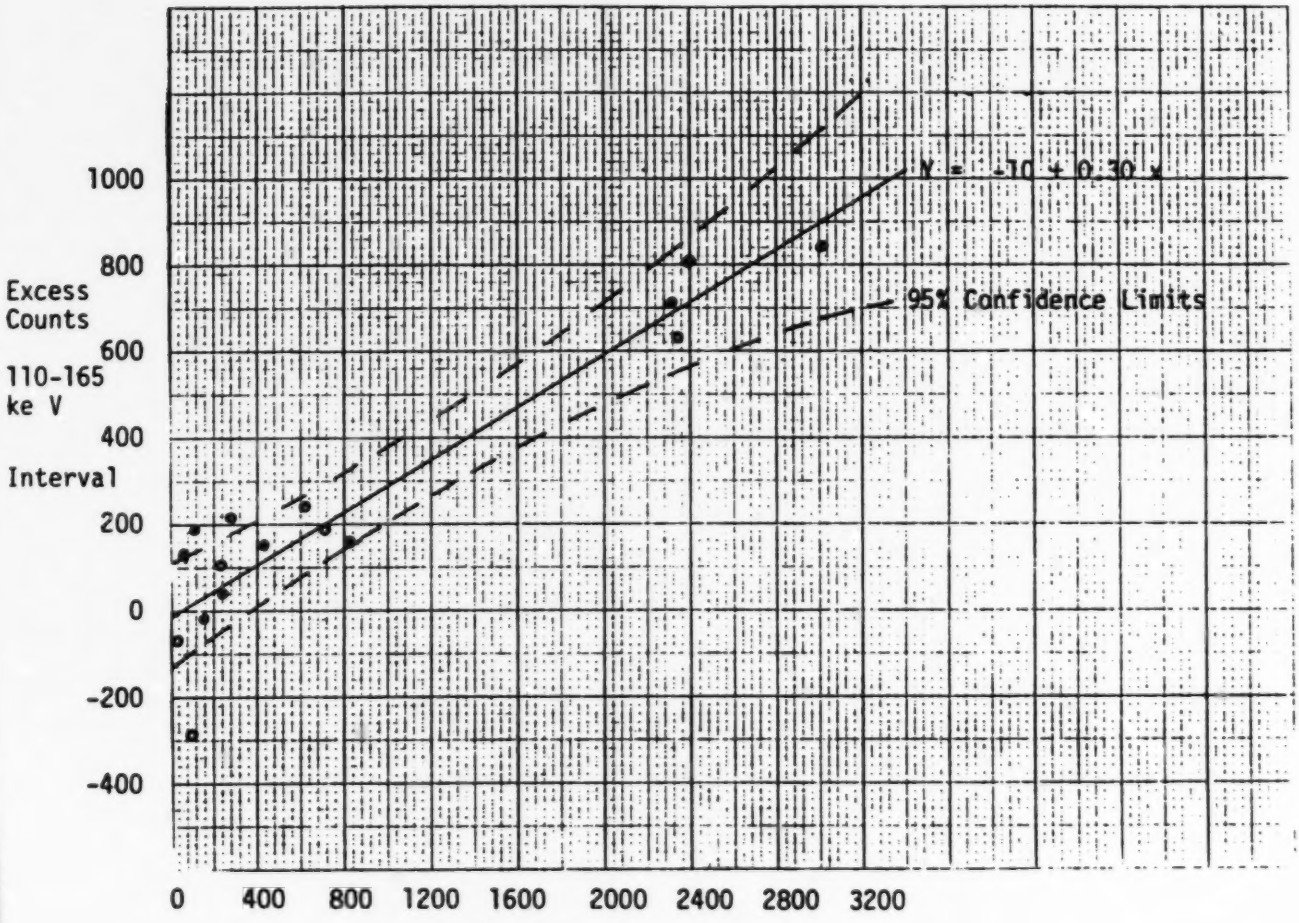


TABLE 1-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 11

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS ug U/L	BOS ug U/h	EOS ug U/L	EOS ug U/h	EOS + 12h ug U/L	EOS + 12h ug U/h	EOS-BOS ug U/L	EOS-BOS ug U/h	EOS-(EOS+12h) ug U/L	EOS-(EOS+12h) ug U/h	(EOS+12h)-BOS ug U/L	(EOS+12h)-BOS ug U/h
Sept 18	6.84	7.89	3	-	6	.254	2	.072	3	-	4	.182		
Sept 19	5.16	5.84	2	.072	3	.060	2	.061	1	-.012	1	-.001		
Sept 20	8.	11.0	2	.061	4	.19	-	-	2	.129	-	-		
Sept 23	4.74	6.3	<2	.052	6	-	-	-	5	-	-	-		
Sept 24	7.16	15.6	-	-	8	.40	-	-	-	-	-	-		
Sept 28	6.94	7.72	<2	.069	2	.068	<2	.072	1	-.001	1	-.003		
Sept 29	8.84	10.5	<2	.072	8	.185	-	-	7	.113	-	-		
OCT 2	8.53	10.2	<2	.048	3	.092	<2	.072	2	.044	1	.02		
OCT 3	5.16	6.19	<2	.072	6	.41	3	.20	5	.34	3	.21		
OCT 4	6.11	7.86	3	.20	5	.31	-	-	2	.11	-	-		
OCT 7	-	-	<2	.066	3	.111	<2	.050	2	.045	2	.06		
OCT 8	4.	4.8	<2	.050	3	.128	-	-	2	.078	-	-		
OCT 12	8.21	10.8	<2	.059	3	.051	<2	.057	2	-.008	2	-.006		
OCT 13	4.69	5.41	<2	.057	2	.085	-	-	1	.028	-	-		
OCT 16	-	-	-	-	-	-	-	-	-	-	-	-		
OCT 17	3.89	5.7	<2	.070	2	.068	<2	.060	1	-.002	1	.008		
OCT 18	3.16	14.	<2	.060	3	.206	56	2.48	2	.146	-	-		
OCT 21	5.98	10.1	56	2.48	11	.72	-	-	-45	-1.76				

<2 ug U/L assumed = 1 ug U/L for correlation purposes

TABLE 1-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT 11

VARIABLE	EOS urine vs ug U inhaled pump on		EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	15.	15.	15.	15.
A	0.40	-.0056	0.24	.0173
B	1.8	.25	2.2	0.060
r	.36	-.05	.37	.30

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 1-3

END OF SHIFT MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 11

VARIABLE	EOS-BOS urine vs ug U inhaled pump on		EOS-BOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	14.	12.	14.	12.
A	.26	-.0057	.082	.0040
B	1.02	.115	1.90	.047
r	.27	-.11	.12	.12

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 1-4

END OF SHIFT MINUS END OF SHIFT PLUS 12 HOURS URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 11

VARIABLE	EOS-(EOS+12h) urine vs ug U inhaled, pump on		EOS-(EOS+12h) urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	7.	7.	7.	7.
A	.040	-.0093	.0107	-.0114
B	1.60	.118	1.77	.147
r	.057	-.17	.018	-.25

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 2-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 12

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS ug U/L	BOS ug U/h	EOS ug U/L	EOS ug U/h	EOS + 12h ug U/L	EOS + 12h ug U/h	EOS-BOS ug U/L	EOS-BOS ug U/h	EOS-(EOS+12h) ug U/L	EOS-(EOS+12h) ug U/h	(EOS+12h)-BOS ug U/L	(EOS+12h)-BOS ug U/h
Sept 18	9.47	11.	–	–	2	.111	<2	.038	–	–	1	.073		
Sept 19	11.1	12.4	<2	.038	4	.191	<2	.115	3	.153	3	.076		
Sept 20	8.	8.97	<2	.115	–	–	–	–	–	–	–	–		
Sept 23	5.47	6.0	<2	.064	3	.142	2	.056	2	.078	1	.086		
Sept 24	23.2	32.4	2	.056	7	.49	–	–	5	-.007	–	–		
Sept 28	28.4	33.	<2	.066	<2	.055	3	.171	0	-.011	-2	-.116		
Sept 29	2.42	2.55	3	.171	–	–	–	–	–	–	–			
OCT 2	28.5	33.6	<2	.045	4	.36	4	.137	3	-.009	0	.22		
OCT 3	8.74	10.7	4	.137	2	.102	<2	.046	-2	-.035	1	.056		
OCT 4	5.9	6.7	<2	.046	2	.076	–	–	1	.030	–	–		
OCT 7	–	–	–	–	–	–	–	–	–	–	–	–		
OCT 8	–	–	–	–	–	–	–	–	–	–	–	–		
OCT 12	11.7	11.9	5	–	8	.48	5	.22	3	–	3	.36		
OCT 13	6.9	9.6	5	.22	3	.151	–	–	-2	-.07	–	–		
OCT 16	10.1	11.8	<2	.047	<2	.088	<2	.028	0	.041	0	.06		
OCT 17	6.5	8.0	<2	.028	–	–	<2	.088	–	–	–	–		
OCT 18	2.6	10.5	<2	.088	<2	.123	–	–	0	.035	–	–		
OCT 21	14.7	18.4	5	.093	6	.34	–	–	1	.25	–	–		

<2 ug U/L assumed = 1 ug U/L for correlation purposes

TABLE 2-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT 12

VARIABLE	EOS urine vs ug U inhaled pump on		EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	13.	13.	13.	13.
A	.073	.0075	.064	.0062
B	2.4	.112	2.3	.101
r	.27	.42	.37	.55

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 2-3

END OF SHIFT MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 12

VARIABLE	EOS-BOS urine vs ug U inhaled pump on		EOS-BOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	12.	11.	12.	11.
A	.102	-.0012	.081	-.00117
B	-.163	.058	-.30	.063
r	.42	-.12	.54	-.19

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 2-4

END OF SHIFT MINUS END OF SHIFT PLUS 12 HOURS URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 12

VARIABLE	EOS-(EOS+12h) urine vs ug U inhaled, pump on		EOS-(EOS+12h) urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	8.	8.	8.	8.
A	-.113	-.0022	-.100	-.0024
B	2.5	.134	2.5	.140
r	-.62	-.15	-.65	-.18

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 3-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 15

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS ug U/L	BOS ug U/h	EOS ug U/L	EOS ug U/h	EOS + 12h ug U/L	EOS + 12h ug U/h	EOS-BOS ug U/L	EOS-BOS ug U/h	EOS-(EOS+12h) ug U/L	EOS-(EOS+12h) ug U/h	(EOS+12h)-BOS ug U/L	(EOS+12h)-BOS ug U/h
Sept 18	10.6	13.3	-	-	4	.27	<2	.21						
Sept 19	10.5	13.0	<2	.21	4	.23	<2	.27						
Sept 20	29.	36.	<2	.27	-	-	-	-						
Sept 23	11.4	14.8	<2	.074	2	.125	<2	.095						
Sept 24	24	34.	<2	.095	6	.25	-	-						
Sept 28	8.7	9.2	<2	.167	3	.19	-	-						
Sept 29	5.9	6.5	-	-	-	-	-	-						
OCT 2	12.2	14.1	<2	.108	4	.25	<2	.102						
OCT 3	6.6	7.7	<2	.102	4	.171	<2	.067						
OCT 4	22.	23.	<2	.067	5	.72	-	-						
OCT 7	6.9	8.2	<2	.195	8	.81	<2	.186						
OCT 8	9.8	11.6	<2	.186	<2	.035	-	-						
OCT 12	12.2	13.1	<2	.094	2	.097	<2	.086						
OCT 13	8.3	10.3	<2	.086	<2	.044	-	-						
OCT 16	71.	82.	<2	.140	13	2.6	<2	.153						
OCT 17	7.4	10.4	<2	.153	2	.072	<2	.121						
OCT 18	8.5	11.8	<2	.121	3	.34	-	-						
OCT 21	6.3	8.6	<2	.167	-	-	-	-						

BOS and EOS+12h urinalysis results too low for meaningfull calculations

TABLE 3-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT 15

VARIABLE	EOS urine vs ug U inhaled pump on		EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	15.	15.	15.	15.
A	.156	.037	.134	.031
B	1.75	-.148	1.67	-.154
r	.82	.92	.81	.90

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 4-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 21

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS		EOS		EOS + 12h		EOS-BOS		EOS-(EOS+12h)		(EOS+12h)-BOS	
			ug U/L	ug U/h	ug U/L	ug U/h	ug U/L	ug U/h	ug U/L	ug U/h	ug U/L	ug U/h	ug U/L	ug U/h
Sept 22	–	–	–	–	–	–	7	.46	–	–	–	–	–	–
Sept 23	–	35.	7	.46	11	.62	–	–	4	.16	–	–	–	–
Sept 27	–	74.	3	.122	11	.75	–	–	8	.63	–	–	–	–
Sept 28	–	71.	–	–	22	1.2	–	–	–	–	–	–	–	–
Oct 1	–	32.	<2	–	6	.91	9	.38	5	–	-3	.53	–	–
Oct 2	–	32.	9	.38	12	.69	<2	.109	3	.31	11	.58	-8	-.27
Oct 3	–	26.	<2	.109	–	–	–	–	–	–	–	–	–	–
Oct 6	–	–	<2	.112	7	.65	–	–	6	.54	–	–	–	–
Oct 11	–	23	<2	.051	9	.89	4	.30	8	.84	5	.59	3	.25
Oct 12	–	6.3	4	.30	4	.20	–	–	0	-.10	–	–	–	–
Oct 15	–	31.	<2	.0122	3	.36	2	.047	2	.35	1	.31	1	.035
Oct 16	–	47.	2	.047	5	.61	<2	.106	3	.56	4	.50	-1	.059
Oct 17	–	18.9	<2	.106	2	.23	–	–	1	.124	–	–	–	–

<2 ug U/L assumed = 1 ug U/L for correlation purposes

TABLE 4-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT 21

VARIABLE	EOS urine vs ug U inhaled pump on		EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	–	–	10.	10.
A	–	–	.188	.0097
B	–	–	1.52	.29
r	–	–	.68	.66

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 4-3

END OF SHIFT MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 21

VARIABLE	EOS-BOS urine vs ug U inhaled pump on ug U/L	EOS-BOS urine vs ug U inhaled pump on ug U/h	EOS-BOS urine vs ug U inhaled on shift ug U/L	EOS-BOS urine vs ug U inhaled on shift ug U/h
n	-	-	9.	8.
A	-	-	.091	.0085
B	-	-	.754	.0743
r	-	-	.61	.56

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 5-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 22

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS ug U/L	BOS ug U/h	EOS ug U/L	EOS ug U/h	EOS + 15h ug U/L	EOS + 15h ug U/h	EOS-BOS ug U/L	EOS-BOS ug U/h	EOS-(EOS+15h) ug U/L	EOS-(EOS+15h) ug U/h	(EOS+15h)-BOS ug U/L	(EOS+15h)-BOS ug U/h
Sept 20	47.	71.	5	-	17	1.51	11	.39	12	-	6	1.12	6	-
Sept 21	65.	73.	11	.39	6	1.04	4	.34	-5	.65	2	.70	-7	-.05
Sept 22	77.	92.	4	.34	13	.66	9	.39	9	.32	4	.27	5	.05
Sept 23	73.	80.	9	.39	6	.74	5	.28	-3	.35	1	.46	-4	-.09
Sept 24	-	-	5	.28	-	-	-	-	-	-	-	-	-	-
Sept 27	164.	212.	-	-	-	-	7	.52	-	-	-	-	-	-
Sept 28	-	-	7	.52	7	.42	14	.56	0	-.10	-7	-.14	7	-.04
Sept 29	25.	40.	14	.56	10	1.43	14	.68	-4	.87	-4	.75	0	.12
Sept 30	16.8	17.3	14	.68	9	.71	6	.36	-5	.03	3	.35	-8	.32
Oct 1	28.	36.	6	.36	8	.70	-	-	2	.34	-	-	-	-
Oct 4	59.	89.	4	.22	11	.93	5	.31	7	.71	6	.62	1	.09
Oct 5	-	-	5	.31	4	.39	5	.27	-1	.08	-1	.12	0	-.04
Oct 6	41.	51.	5	.27	4	.67	4	.28	-1	.40	0	.39	-1	.01
Oct 7	46.	54.	4	.28	3	.36	23	1.21	-1	.08	-20	-.85	19	.93
Oct 8	72.	54.	23	1.21	30	1.14	-	-	7	-.07	-	-	-	-
Oct 11	29.	37.	11	.31	9	.57	9	.43	-2	.26	0	.14	-2	.12
Oct 12	29.	37.	9	.47	8	.63	5	.31	-1	.20	3	.32	-4	-.12
Oct 13	34.	44.	5	.31	6	.57	6	.52	1	.26	0	.05	1	.21
Oct 14	16.8	17.	6	.52	4	.54	4	.27	-2	.02	0	.27	-2	-.25
Oct 15	39.	40.	4	.27	8	.69	-	-	4	.42	-	-	-	-
Oct 18	106.	118.	4	.112	7	.94	5	.25	3	.82	2	.69	1	.14
Oct 19	66.	75.	5	.25	6	.70	6	.40	1	.50	0	.30	1	.15
Oct 20	1340.	1350.	6	.40	100	12.3	8	.38	94	11.9	92	11.9	2	-.02
Oct 21	663.	930.	8	.38	-	-	-	-	-	-	-	-	-	-

<2 ug U/L assumed = 1 ug U/L for correlation purposes

TABLE 5-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT 22

VARIABLE	EOS urine vs ug U inhaled pump on		EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	18. 19.	18. 19.	18. 19.	18. 19.
A	.060 .070	.0026 .0089	.023 .070	.27 .0088
B	6.3 5.8	.68 .38	7.9 5.2	.69 .31
r	.24 .96	.20 .99	.10 .96	.27 .99

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

Note: One data point is widely removed from the others and the affect of including this point in the analysis is shown above.

TABLE 5-3

END OF SHIFT MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 22

VARIABLE	EOS-BOS urine vs ug U inhaled pump on		EOS-BOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	18	17	18	17
	19	18	19	18
A	.080	.0042	.083	.0058
	.072	.0089	.072	.0089
B	-2.6	.161	-3.5	.039
	-2.3	-.066	-2.9	-.135
r	.40	.38	.45	.57
	.98	.99	.98	.996

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

Note: One data point is widely removed from the others and the effect of including this point in the analysis is shown above.

TABLE 5-4

END OF SHIFT MINUS END OF SHIFT PLUS 15 HOURS URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 22

VARIABLE	EOS-(EOS+15h) urine vs ug U inhaled, pump on		EOS-(EOS+15h) urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	9 10	9 10	9 10	9 10
A	.118 .072	.0064 .0090	.191 .073	.011 .0090
B	-7.5 -4.6	-.0033 -.168	-14.8 -5.6	-.45 -.30
r	.30 .97	.24 .99	.49 .97	.41 .99

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

Note: One data point is widely removed from the others and the affect of including this point in the analysis is shown above.

TABLE 5-5

END OF SHIFT PLUS 15 HOURS MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 22

VARIABLE	(EOS+15h)-BOS urine vs ug U inhaled, pump on		(EOS+15h)-BOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	9 10	8 9	9 10	8 9
A	-.116 -.0005	-.0052 -.00015	-.099 -.00049	-.0052 -.00015
B	9.8 2.4	.50 .165	10.1 2.4	.57 .167
r	-.31 -.03	-.32 -.20	-.27 -.03	-.34 -.20

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

Note: One data point is widely removed from the others and the effect of including this point in the analysis is shown above.

TABLE 6-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 24

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS ug U/L	BOS ug U/h	EOS ug U/L	EOS ug U/h	EOS + 15h ug U/L	EOS + 15h ug U/h	EOS-BOS ug U/L	EOS-BOS ug U/h	EOS-(EOS+15h) ug U/L	EOS-(EOS+15h) ug U/h	(EOS+15h)-BOS ug U/L	(EOS+15h)-BOS ug U/h
Sept 20	80.	119.	6	.38	11	.70	4	.43	5	.32	7	.27	-2	.05
Sept 21	-	-	4	.43	10	.48	7	.46	6	.05	3	.02	3	.03
Sept 22	-	-	7	.46	5	-	5	.46	-2	-	0	-	-2	0.
Sept 23	-	-	5	.46	-	-	12	.67	-	-	-	-	7	.21
Sept 24	-	-	12	.67	21	1.30	-	-	9	.63	-	-	-	-
Sept 27	-	-	3	.21	10	.71	9	.47	7	.51	1	.24	6	.26
Sept 28	-	-	9	.47	9	.74	3	.22	0	.27	6	.52	-6	-.25
Sept 29	74.	89.	3	.22	13	1.19	-	-	10	.97	-	-	-	-
Sept 30	41.	42.	-	-	9	.74	6	.37	-	-	3	.37	-	-
Oct 1	66.	77.	6	.37	10	.73	-	-	4	.36	-	-	-	-
Oct 4	-	-	3	.24	10	.80	-	-	7	.56	-	-	-	-
Oct 5	26.	32.	-	-	-	-	11	.59	-	-	-	-	-	-
Oct 6	32.	51.	11	.59	14	.55	17	1.07	3	-.04	-3	.44	6	.48
Oct 7	40.	53.	17	1.07	-	-	24	1.27	-	-	-	-	7	.20
Oct 8	-	-	24	1.27	14	.83	-	-	-10	-.44	-	-	-	-
Oct 11	-	-	3	.21	35	1.04	7	.48	32	.83	28	.56	4	.27
Oct 12	63.	72.	7	.48	15	.71	4	.39	8	.23	11	.32	-3	-.09
Oct 13	24.	44.	4	.39	7	.55	<2	.105	3	.16	6	.45	-3	-.29
Oct 14	42.	46.	<2	.105	8	.62	3	.21	7	.515	5	.41	2	.20
Oct 15	-	-	3	.21	11	.73	-	-	8	.52	-	-	-	-
Oct 18	68.	66.	<2	.075	28	1.01	11	.92	27	.935	17	.09	10	.84
Oct 19	55.	56.	11	.92	8	.65	14	1.17	-3	-.27	-6	-.52	3	.25
Oct 20	77.	78.	14	1.17	16	.74	9	.62	2	-.43	7	.12	-5	-.55
Oct 21	-	-	9	.62	10	.66	-	-	1	.04	-	-	-	-

<2 ug U/L assumed = 1 ug U/L for correlation purposes

TABLE 6-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT

VARIABLE	EOS urine vs ug U inhaled pump on		EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	11	11	11	11
A	.133	.0043	.051	.0034
B	5.14	.52	9.19	.52
r	.43	.56	.20	.41

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 6-3

END OF SHIFT MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 24

VARIABLE	EOS-BOS urine vs ug U inhaled pump on		EOS-BOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h	ug U/L	ug U/h
n	10	10	10	10
A	.106	.0046	.030	.0040
B	.42	.0063	4.5	.00076
r	.26	.20	.08	.20

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 7-1

SUMMARY OF PERSONAL AIR SAMPLING AND URINALYSIS RESULTS FOR SUBJECT 25

Shift	ug U inhaled pump on	ug U inhaled on shift	BOS ug U/L	BOS ug U/h	EOS ug U/L	EOS ug U/h	EOS + 13h ug U/L	EOS + 13h ug U/h	EOS-BOS ug U/L	EOS-BOS ug U/h	EOS-(EOS+13h) ug U/L	EOS-(EOS+13h) ug U/h	(EOS+13h)-BOS ug U/L	(EOS+13h)-BOS ug U/h
Sept 20		-	3	-	4	.32	2	.074	1	-	2	.25	-1	-
Sept 21		26.	2	.074	<2	.088	2	.064	-1	.014	-1	.024	0	-.010
Sept 22		20.	2	.064	4	.20	<2	.021	2	.136	3	.18	-1	-.043
Sept 23		11.6	<2	.021	5	.23	<2	.029	4	.21	4	.20	0	.008
Sept 24		-	<2	.029	8	.48	-	-	7	.45	-	-	-	-
Sept 27		16.4	<2	.025	3	.104	3	.102	2	.08	0	.002	2	.077
Sept 28		-	3	.102	2	.126	4	.171	-1	.024	-	-	-	-
Sept 29		-	4	.171	2	.144	<2	.037	-2	-.027	1	.11	-3	-.134
Sept 30		22.	<2	.037	7	.20	4	.104	6	.163	3	.10	3	.067
Oct 1		13.7	4	.104	5	.20	-	-	1	.10	-	-	-	-
Oct 4		-	<2	.042	4	.153	2	.063	3	.111	2	.09	1	.021
Oct 5		21.	2	.063	5	.23	2	.049	3	.167	3	-	-	-
Oct 6		24.	2	.049	5	.38	<2	.016	3	.33	4	.36	-1	-.033
Oct 7		8.8	<2	.016	3	.182	<2	.022	2	.166	2	.16	0	.006
Oct 8		.74	<2	.022	10	.32	-	-	9	.30	-	-	-	-
Oct 12		24.	<2	.027	17	.63	6	.168	16	.60	11	.46	5	.141
Oct 13		12.4	6	.168	3	.180	<2	.035	-3	.012	2	.145	-5	-.133
Oct 14		-	<2	.035	<2	.108	<2	-	0	.073	0	-	0	-
Oct 15		15.8	<2	-	4	.21	-	-	3	-	-	-	-	-
Oct 18		23.	<2	.043	8	.41	3	.092	7	.37	5	.32	2	.049
Oct 19		-	3	.092	4	.191	4	.119	1	.10	0	-	1	-
Oct 20		3.2	4	.119	3	.112	<2	.028	-1	-.007	2	.084	-3	-.091
Oct 21		9.1	<2	.028	2	.162	-	-	1	.134	-	-	-	-

<2 ug U/L assumed = 1 ug U/L for correlation purposes

TABLE 7-2

END OF SHIFT URINALYSIS VS INHALED URANIUM CORRELATIONS FOR SUBJECT 25

VARIABLE	EOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h
n	16	16
A	.087	.0060
B	3.9	.145
r	.17	.33

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 7-3

END OF SHIFT MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 25

VARIABLE	EOS-BOS urine vs ug U inhaled on shift: ug U/L	ug U/h
n	16	16
A	.124	.0063
B	1.43	.09
r	.21	.31

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

x/y = values calculated from regression curve

r = correlation coefficient

TABLE 7-4

END OF SHIFT MINUS END OF SHIFT PLUS 12 HOURS URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 25

VARIABLE	EOS-(EOS+13h) urine vs ug U inhaled on shift	
	ug U/L	ug U/h
n	11	11
A	.11	.0070
B	1.27	.063
r	.26	.36

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 7-5

END OF SHIFT PLUS 12 HOURS MINUS BEGINNING OF SHIFT URINE VS INHALED URANIUM CORRELATIONS FOR SUBJECT 25

VARIABLE	(EOS+13h)-BOS urine vs ug U inhaled on shift	
	ug U/L	ug U/h
n	11	11
A	.21	.0005
B	-3.4	-.087
r	.55	.49

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

TABLE 8-1

SUMMARY OF CORRELATION COEFFICIENTS FOR SPOT URINALYSIS AND PERSONAL AIR SAMPLES (INHALATION DURING SHIFT)

SUBJECT	11	12	15	21	22	24	25
PARAMETER							
EOS ug U/L	0.37	0.37	0.81*	0.68*	0.96*	0.20	0.17
EOS ug U/h	0.30	0.55*	0.90*	0.66*	0.99*	0.41	0.33
EOS-BOS ug U/L	0.12	0.54*	-	0.61*	0.98*	0.08	0.21
EOS-BOS ug U/h	0.12	-.19	-	0.56	0.99*	0.20	0.31
(EOS+Xh) -BOS ug U/L	-	-	-	-	-.03	-	0.55*
(EOS+Xh) -BOS ug U/h	-	-	-	-	-.20	-	0.49
EOS- (EOS+Xh) ug U/L	0.02	-.65*	-	-	0.97*	-	0.26
EOS- (EOS+Xh) ug U/h	-.25	-.18	-	-	0.99*	-	0.36

NOTE: Only correlation coefficients marked * are significant at the 90 % confidence level or higher.

TABLE B-2

SUMMARY OF CORRELATION COEFFICIENTS FOR SPOT URINALYSIS AND PERSONAL AIR SAMPLES (INHALATION WHILE PUMP ON)

SUBJECT	11	12	15	21	22	24	25
PARAMETER							
EOS ug U/L	0.36	0.27	0.82*	-	0.96*	0.43	-
EOS ug U/h	-.05	0.42	0.92*	-	0.99*	0.56*	-
EOS-BOS ug U/L	0.27	0.42	-	-	0.98*	0.26	-
EOS-BOS ug U/h	-.11	-.12	-	-	0.99*	0.20	-
(EOS+Xh) -BOS ug U/L	-	-	-	-	-.03	-	-
(EOS+Xh) -BOS ug U/h	-	-	-	-	-.20	-	-
EOS- (EOS+Xh) ug U/L	0.06	-.62	-	-	0.97*	-	-
EOS- (EOS+Xh) ug U/h	-.17	-.15	-	-	0.99*	-	-

NOTE: Only correlation coefficients marked * are significant at the 90 % confidence level or higher.

TABLE 9

LUNG COUNTING MEASUREMENTS FOR SUBJECT 11

Measurement No.	Subject	Integrated Counts in Spectral Region 10-38keV	38-110keV	110-165keV	165-204keV	204-Max. keV
9-23-1	11	1677	10529	5091	2021	1666
9-23-2	phantom	1220	7754	4330	1793	1576
9-30-1	11	1423	8821	4201	1514	1333
9-30-2	phantom	973	5910	3344	1323	1123
10-04-1	11	1528	9934	4620	1773	1500
10-04-2	phantom	1179	6873	3784	1427	1314
10-12-5	11	1598	9116	4458	1728	1372
10-12-7	phantom	1027	6354	3550	1478	1160
10-22-5	11	1542	9103	4315	1568	1406
10-22-6	phantom	1071	6132	3511	1375	1136

CORRELATIONS FOR EACH ENERGY INTERVAL FOR SUBJECT LUNG AND WATER PHANTOM COUNTS

n	5	5	5	5	5
A	.619	.950	.899	1.024	.682
B	876	3223	1207	206	595
r	.68	.98	.99	.95	.98

n = number of data sets used in correlation

A = slope of the linear regression curve

B = y intercept of the linear regression curve

r = correlation coefficient

NOTE: Only correlation coefficients >0.82 are significant at the 90 % confidence level for 5 data points.

TABLE 10

SUBJECT 11 LUNG COUNT DATA COMPARED TO REGRESSION CURVE

Counts in 38-110 keV Region

Phantom	Measured Subject 11	Predicted * Subject 11	$\lvert\Delta\rvert$ Subject 11 Measured − Predicted
7754	10529	10593	64
5910	8821	8840	19
6873	9934	9756	178
6354	9116	9262	146
6132	9103	9051	52

sample variance $S^2 = \dfrac{\sum |\Delta|^2}{n-2}$

sample standard deviation $S = 141$ counts

$S = 1.64$ mg U (using calibration factor from [Ref. 2])

* Using $y = 3223 + 0.95\,x$

where y = subject 11 counts

x = phantom counts

MATHEMATICAL METHODS

The formulae and references for the various mathematical techniques utilized in the preparation of this report are given below.

A1 LINEAR REGRESSION ANALYSIS BY LEAST SQUARES [Ref 5]

Suppose that n pairs of measurements $(x1, y1), (x2, y2), \ldots (xn, yn)$ are made on the two variables x and y. If the data approximates a straight line it can be represented by the equation

$$y = A + Bx. \qquad \text{(A-1)}$$

A and B are coefficients which must be estimated such that the line gives a good fit to the data. In this report the method of least squares has been used based upon the equations

$$B = \frac{n\sum x_i\, y_i - \sum y_i \sum x_i}{n\sum x_i^2 - (\sum x_i)^2} \qquad \text{(A-2)}$$

$$A = \frac{\sum y_i}{n} - B\,\frac{\sum x_i}{n}. \qquad \text{(A-3)}$$

The coefficients A and B follow the t-distribution and therefore, the 100(1-a) per cent confidence intervals are

for A

$$A \pm t_{\frac{1}{2}a,n-2}\, S_{y|x}\left\{\frac{1}{n} + \frac{\bar{x}^2}{\sum(x_i - \bar{x})^2}\right\}^{1/2} \qquad \text{(A-4)}$$

and for B

$$B \pm t_{\frac{1}{2}a,n-2}\, S_{y|x}\left\{\sum(x_i - \bar{x})^2\right\}^{-\frac{1}{2}} \qquad \text{(A-5)}$$

where

$$\bar{x} = \sum x_i / n .$$

Also the confidence interval for $A + Bx'$, where x' is a specific value of x, is given by

$$A + Bx' \pm t_{\frac{1}{2}a,n-2}\, S_{y|x}\left\{\frac{1}{n} + \frac{(x' - \bar{x})^2}{\sum(x_i - \bar{x})^2}\right\}^{1/2} \qquad \text{(A-6)}$$

Note that the confidence interval is shortest when $x' = \bar{x}$.

In the above equations

$$S_{y|x} = \left\{ \frac{\sum y_i^2 - A\sum y_i - B\sum x_i y_i}{n-2} \right\}^{1/2} \qquad \text{(A-7)}$$

A2 CORRELATION ANALYSIS [Ref 2]

For samples of size n from bivariate normal populations of paired data (x1, y1), (x2, y2), ... (xn, yn), the sample correlation coefficient, r, is given by:

$$r = \frac{n\sum x_i y_i - (\sum x_i)(\sum y_i)}{\left\{n\sum x_i^2 - (\sum x_i)^2\right\}^{1/2}\left\{n\sum y_i^2 - (\sum y_i)^2\right\}^{1/2}}. \qquad \text{(A-8)}$$

r is a measure of the degree of the linear relationship between x and y. When r = 0 the two random variables are uncorrelated. If the data points actually fall on a straight line then r = +1 or -1 depending on whether the line has a positive or negative slope, respectively.

Test of hypothesis concerning r can be made using the variable:

$$z = \frac{(n-3)^{1/2}}{2} \ln \frac{(1+r)(1-g)}{(1-r)(1+g)} \qquad \text{(A-9)}$$

which has approximately the standard normal distribution. Suppose for example, that the correlation coefficient r was calculated to be 0.50 for a set of 12 data points. To test the null hypothesis, that the correlation coefficient is zero, against the alternative hypothesis that the correlation coefficient is different than zero, substitute r = 0.50 and g = 0 into A-9. The result is z = 1.65 which equals $z_{.05} = 1.65$ from the normal distribution tables. Therefore, the null hypothesis can be rejected at the 90 % confidence level but with no higher confidence.

Critical values of the correlation coefficients were calculated using equation A-9 and are shown in Table A-1. Only correlation coefficients greater than the critical values are significantly different than zero at the 90 and 95 % confidence levels for the indicated number of data sets.

TABLE A-1

CRITICAL VALUES FOR CORRELATION COEFFICIENTS

Number of data sets	Critical Values of Correlation Coefficients for significance at Confidence Levels	
	at 90 %	at 95 %
16	0.42	0.49
15	0.44	0.51
14	0.46	0.53
13	0.48	0.55
12	0.50	0.57
11	0.53	0.60
10	0.55	0.62
9	0.59	0.66
8	0.63	0.70
7	0.68	0.75
6	0.74	0.81
5	0.82	0.89

POOR

QUALITY

ORIGINAL